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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-24

AQUATIC DISPOSAL FIELD INVESTIGATIONS DUWAMISH WATERWAY DISPOSAL SITE PUGET SOUND, WASHINGTON.

APPENDIX B. ROLE OF DISPOSAL OF PCB-CONTAMINATED SEDIMENT IN THE ACCUMULATION OF PCB'S BY MARINE ANIMALS.

by

(10) Virginia F. Stout Laura G. Lewis

Northwest and Alaska Fisheries Center
Seattle, Washington 98104

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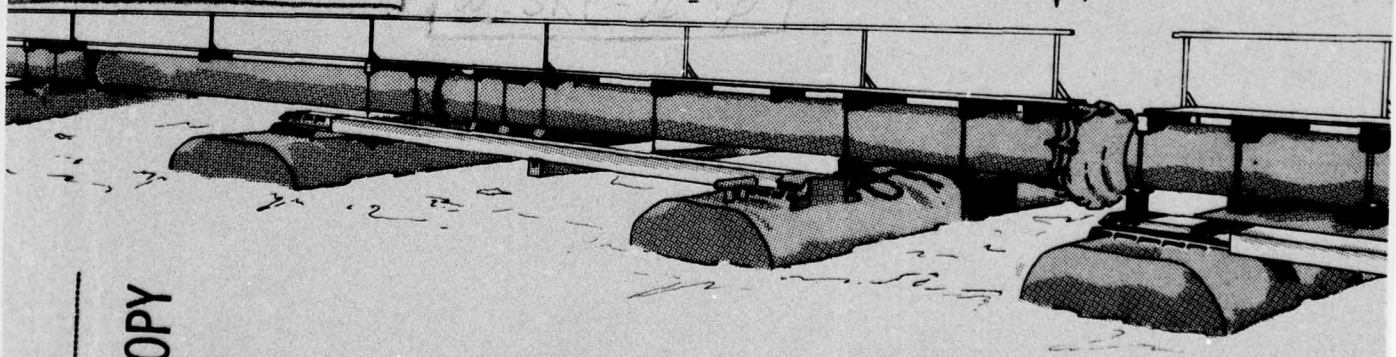

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Under Interagency Agreement WESRF 76 - 90
(DMRP Work Unit No. 1A10B)

Monitored by Environmental Effects Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

AQUATIC DISPOSAL FIELD INVESTIGATIONS
DUWAMISH WATERWAY DISPOSAL SITE
PUGET SOUND, WASHINGTON

Appendix A: Effects of Dredged Material Disposal on Demersal Fish and Shellfish in Elliott Bay, Seattle, Washington

Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals

Appendix C: Effects of Dredged Material Disposal on the Concentration of Mercury and Chromium in Several Species of Marine Animals

Appendix D: Chemical and Physical Analyses of Water and Sediment in Relation to Disposal of Dredged Material in Elliott Bay

Appendix E: Release and Distribution of Polychlorinated Biphenyls Induced by Open-Water Dredge Disposal Activities

Appendix F: Recolonization of Benthic Macrofauna over a Deep-Water Disposal Site

Appendix G: Benthic Community Structural Changes Resulting from Dredged Material Disposal, Elliott Bay Disposal Site

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESYV

30 November 1977

SUBJECT: Transmittal of Technical Report D-77-24 (Appendix B)

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (work units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations, of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 1A is a part of the Environmental Impacts and Criteria Development Project (EICDP), which has as a general objective determination of the magnitude and extent of effects of disposal sites on organisms and the quality of surrounding water, and the rate, diversity, and extent that such sites are recolonized by benthic flora and fauna. The study reported herein was an integral part of a series of research contracts jointly developed to achieve the EICDP general objective at the Duwamish Waterway Disposal Site, one of eight study sites located in several geographical regions of the United States. Consequently, this report presents results and interpretations of but one of several closely interrelated efforts and should be used only in conjunction with and consideration of the other related reports for this site.

2. This report, Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals, is one of seven appendices published relative to the Waterways Experiment Station Technical Report D-77-24 entitled: Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington. The titles of all appendices of this series are listed on the inside front cover of this report. The main report provides results, interpretations, and conclusions not found in the individual appendices and provides a comprehensive summary and synthesis overview of the entire project.

3. The purpose of this study, conducted as Work Unit 1A10B, was to determine whether PCB's in dredged material were transferred to marine organisms either during or after an open-water disposal operation. The PCB content of indigenous animals and animals caged at the disposal site was determined. The data indicated that the dredged material disposal operation resulted in no obvious or statistically significant increases in the PCB levels of the marine organisms studied.

4. The authors note the predominant influence of the Duwamish River on the Elliott Bay disposal site and the relatively high concentrations of PCB's found in the indigenous experimental animals. They suggest that because of these problems it was not possible to ascertain whether or not the marine animals accumulated PCB's to significant levels as a result of the disposal operation. However, the data show that only one animal, the mussel *Mytilus edulis*, of seven investigated accumulated PCB's to levels above preexposure values.

5. The results of this study are important in determining placement of dredged material for open-water disposal. Referenced studies, as well as the ones summarized in this report, will aid in determining the optimum disposal conditions and site selection for either the dispersion of the material from the dump site or for its retention within the confines of the site, whichever is preferred for maximum environmental protection at a given site.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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This report describes studies concerning the possible transfer to marine animals of polychlorinated biphenyls (PCB's) as a result of the open-water disposal of PCB-laden dredged material. Dredged material from the Duwamish River in Seattle, Washington, was deposited at an experimental site in nearby Elliott Bay. The PCB content of indigenous animals, English sole (Parophrys vetulus) and Alaska and Oregon pink shrimp (Pandalus borealis and P. jordani), and animals caged at the site, spot shrimp (P. platyceros), sea cucumber (Parastichopus

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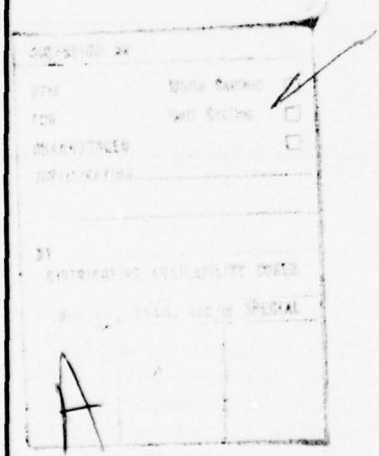
californicus), and mussel (Mytilus edulis) was determined. It was not possible to ascertain whether or not marine animals concentrate PCB's as the result of deposition of PCB-laden dredged material. The small increase in PCB level observed in mussels may have been related to the flux of PCB's resulting from the disposal operation. Alternatively, it may have issued from the PCB burden normally carried downstream by the Duwamish River. These data indicate that no obvious changes have occurred in the PCB levels in marine animals in Elliott Bay as the result of depositing PCB-laden dredged material at the experimental site.



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EXECUTIVE SUMMARY

The possible transfer of polychlorinated biphenyls (PCB's) from PCB-laden dredged material to marine animals was investigated. Material dredged from the Duwamish River, Seattle, Washington, an area known to be polluted with PCB's, was deposited in nearby Elliott Bay.

The PCB levels in English sole (Parophrys vetulus) and Alaska pink shrimp (Pandalus borealis) collected in the disposal area were determined before disposal began and at intervals up to 9 months afterward. English sole collected before disposal operations contained more PCB's than immediately following disposal. Sole were not available subsequently until 9 months later, when only a limited number appeared. Alaska pink shrimp were available throughout the study at the disposal site, but were sometimes missing from the reference site. No change in PCB levels related to disposal was apparent in pink shrimp. Variation between replicate samples may have masked changes.

Marine animals in cages on the experimental site were also exposed to the PCB-laden dredged material. Spot shrimp (Pandalus platyceros) were exposed for 3 days during the disposal operation. They did not accumulate PCB's above the rather high level, 0.17 ppm, present prior to disposal. Sea cucumbers (Parastichopus californicus) and mussels (Mytilus edulis) were exposed for up to 3 weeks after dumping ceased. Sea cucumbers contained 0.04 ppm initially; they did not concentrate PCB's. Mussels did accumulate PCB's to a slight extent, 0.21 ppm final concentration, but the increase was not statistically significant because of the variability between samples and the elevated initial level, 0.12 ppm. The mussel data do, however, indicate that the experimental disposal operation did not create an enduring flux of PCB's; otherwise, the mussels would have accumulated PCB's to a greater extent.

These data indicate that no obvious changes have occurred in the PCB levels in marine animals in Elliott Bay as the result of depositing PCB-laden dredged material at the experimental site.

In future studies, the use of animals with lower initial PCB levels, a larger number of animals in each sample, a more uniform size of animals within the sample groups, and more extensive baseline studies to enable choice of species present throughout the year would reduce the variability in samples and might result in more readily interpretable data.

PREFACE

This report presents the results of a study to determine the effects of open-water disposal of dredged material from the Duwamish Waterway into Elliott Bay upon the concentration of polychlorinated biphenyls in five species of marine animals indigenous to Puget Sound.

The study was prepared for the Office, Chief of Engineers, and supported by the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Effects Laboratory (EEL), Vicksburg, Mississippi, under Interagency Agreement WESRF 76-90 to the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, Washington. The report forms part of the EEL Dredged Material Research Program (DMRP).

The report was written by Dr. Virginia F. Stout, Utilization Research Division, Northwest and Alaska Fisheries Center. Samples were prepared and analyzed for polychlorinated biphenyls by the authors. Robert Shepp, former employee of this Division of the National Marine Fisheries Service, assisted in preparing the samples. The specimens were provided by George Snyder, John R. Hughes, Warren E. Ames, Herbert Sanborn, Benjamin Patten, and Suanne Y. Smith of the Environmental Conservation Division of the Northwest and Alaska Fisheries Center. The interlaboratory calibration was performed at the University of Washington, Department of Oceanography, Seattle, Washington, in the laboratory of Dr. Spyros Pavlou, Dr. Robert Dexter, and Mr. Andrew Hafferty.

The study was conducted under the direction of the following EEL personnel: Dr. R. M. Engler, Environmental Impacts and Criteria Development Project, Project Manager; J. R. Reese and Jeffrey H. Johnson, Site Managers; and Dr. Henry E. Tatem, coordinator of the site report. The study was under the general supervision of Dr. John Harrison, Chief, EEL.

Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was F. R. Brown.

CONTENTS

AQUATIC DISPOSAL FIELD INVESTIGATIONS

DUWAMISH WATERWAY DISPOSAL SITE, PUGET SOUND, WASHINGTON

APPENDIX B: ROLE OF DISPOSAL OF PCB-CONTAMINATED SEDIMENT IN THE ACCUMULATION OF PCB'S BY MARINE ANIMALS

PART I: INTRODUCTION

1. Numerous papers confirm the nearly universal presence of PCB's (polychlorinated biphenyls) in the marine environment.[1,2] Marine animals accumulate this type of material from water, sediment, and food. These lipophilic substances readily cross both gill and intestinal membranes, and transfer through the skin may also occur. Accumulation of chlorinated hydrocarbons is proportional to the concentration in the marine environment. Increases in the level of PCB's in marine animals are associated with industrial facilities, maritime activities, and urbanization. The role of PCB-laden dredged material in biological transfer of this pollutant has not been well documented. Experiments designed to assess this problem are described in this report.

2. The Environmental Effects Laboratory (EEL) of the U. S. Army Engineer Waterways Experiment Station (WES) is completing a multi-faceted research program on the disposal in Elliott Bay of material dredged from the Duwamish River, Seattle, Washington. This study was designed to provide more definitive information on numerous environmental aspects of dredging and disposal operations, in conjunction with other major aquatic disposal field investigations in Lake Erie, Long Island Sound, the Gulf of Mexico, and off the mouth of the Columbia River.

3. The Duwamish River has been known for some time (but only recently published[3]) to contain a high level of PCB's (5.1 ppm dry weight in sediment) compared to less than 0.02 ppm at an uncontaminated site nearby.*

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* Personal communication, March 1976, Dr. B. B. McCain, Microbiologist, Northwest and Alaska Fisheries Center.

These issue from municipal, industrial, and maritime waste disposal, as well as from a spill in 1974. The material dredged from the river channel, therefore, is presumed to be heavily contaminated with PCB's. The material from the river channel provided a suitable opportunity for determining whether PCB's in dredged material transfer to marine organisms either during the disposal operation or from the deposits on the disposal site. (PCB levels in the river sediment prior to dredging, as well as in water and sediment at the experimental disposal site before and after dumping, are the subject of other reports (Appendices D and E).)

4. Both temporary fluxes and prolonged contamination of the marine environment by chlorinated hydrocarbon pollutants can be evaluated by studying the occurrence of these compounds in marine animals, which concentrate them as much as 100,000 fold from the surrounding environment. American oysters (Crassostrea virginica) accumulated 101 ppm PCB's during exposure for 25 weeks to 0.001 ppm PCB's dissolved in seawater.[4] They lost it rapidly when exposure ceased and after 12 weeks in PCB-free water contained no detectable residue (less than 0.2 ppm). Mollusks generally reflect short-term exposure and fluctuations of these compounds in the environment. Fish, in contrast, retain these pollutants for a long period of time and reflect longer term exposures. Presumably these fat-soluble substances remain in the adipose tissue and are not readily mobilized. If exposure to the pollutant does not continue or recur, there is an apparent loss of the pollutant in a growing animal simply because of dilution in the adipose tissue of a constant amount of chlorinated hydrocarbon.

5. Oysters, clams, and mussels were used as indicators of pollution by chlorinated hydrocarbons in estuaries throughout the United States[5] in an 8-year study of monthly levels of these substances. Mussels (Mytilus edulis and M. californianus) and Dover sole (Microstomus pacificus) have been used to monitor PCB's in the waters of southern California.[6] Mussels (M. edulis) and sculpin (Leptocottus armatus, Oligocottus maculosus, and others) have been used in southern Puget

Sound.[7]

6. Nimmo and co-workers[8] studied the transfer of PCB's from sediments to marine organisms both in the laboratory and under natural conditions. Fiddler crabs (Uca minax) and pink shrimp (Penaeus duorarum) were exposed in aquaria to sediments contaminated with PCB's by an industrial spill. The concentration in the animals depended on the initial level in the sediment and the type of sediment. Organic material in sediment tightly binds chlorinated hydrocarbons. Animals exposed to silt accumulated less PCB's than those exposed to sandy silt, which released more of these chemicals into the water. After 30 days, fiddler crabs accumulated 3.2 to 80 ppm PCB's and pink shrimp 0.2 to 240 ppm (in the hepatopancreas) from contaminated sediments containing 1.4 to 61 ppm PCB's (dry weight). Grass shrimp (Palaemonetes pugio) caged in Escambia Bay, Florida, downstream from an actual spill, accumulated only a tenth as much, 0.41 and 0.42 ppm in 1 and 3 months, respectively, from sediment containing 5 ppm PCB's (dry weight).[9]

7. Grass shrimp in the field study appeared to have reached an equilibrium concentration of PCB's within 1 month. Exposure to PCB's in water in an aquarium, however, did not produce equilibrium in 35 days. The grass shrimp in the aquaria lost 50 to 90 percent of the PCB's in 4 weeks in PCB-free water. Blue crabs (Callinectes sapidus) exposed to 0.005 ppm PCB's in seawater in aquaria for 20 days lost only half the accumulated material during 4 weeks in PCB-free water, from 23 to 11 ppm.[10]

8. Dover sole (Microstomus pacificus) were exposed for 13 months in aquaria to sediment from the Palos Verdes, California, sewer outfall.[11] The sediment contained 6.0 ppm PCB's (dry weight). Although muscle tissue showed no increase in PCB content, the livers contained approximately 20 times as much PCB's as those from control animals.

9. In conjunction with the study reported here, approximately 114,250 m^3 of Duwamish River sediment was deposited at a 366 X 366 m experimental site (47°35'41"N, 122°21'42" W) in the southern part of

Elliott Bay, approximately 800 m north of the mouth of the West Waterway of the Duwamish River, during the period 17 February to 6 March 1976. The site is on the river delta in about 60 m of water. The sediments contain sand, silt, clay, and wood chips. No records of previous dredged material disposal on the site exist, but accidental drops may have occurred.

10. Two species of animals inhabiting the experimental site and three species native to Puget Sound and suitable for holding in cages were used as test organisms to study effects of exposure on levels of PCB's in animal tissue. English sole (Parophrys vetulus) and Alaska pink shrimp (Pandalus borealis) were chosen as representative demersal organisms after evaluation of a preliminary trawl study in December 1975. Both species were to be collected at the sites before dredging began and approximately 2 weeks and 1, 3, 6, and 9 months after disposal ceased. Few English sole, however, were present after the 2-week sampling. Trial grabs showed that benthic invertebrates such as polychaete worms and mollusks, primary consumers and part of the food chain, were not present in adequate numbers at the relatively barren disposal site to provide enough tissue for analyses.

11. Spot shrimp (Pandalus platyceros), sea cucumbers (Parastichopus californicus), and mussels (Mytilus edulis) were exposed to the PCB's in the dredged material in cages set on the bottom of Elliott Bay. The concentration of PCB's in the water column presumably was highest during disposal. Spot shrimp were used to evaluate the effect of this flux of PCB's on benthic organisms. The shrimp were placed at the periphery of the disposal site, since a direct hit of the cohesive material would have destroyed the cage. They were exposed for 3 days. Sea cucumbers and mussels were planted for a more extended period directly on the disposal site immediately following the cessation of disposal operations. Animals were removed after 1, 2, and 3 weeks to assess the longer term levels of PCB's at the disposal site. Mussels and sea cucumbers were chosen in part because corresponding native

invertebrates were not available at the experimental site. Furthermore, the depth of the site, about 60 m, limited the choice to those animals that could survive capture and exposure at this depth. Although mussels are intertidal animals, they have been exposed underwater at depths to 35 m.[12] Sea cucumbers had not been used before in this type of study.

12. A reference bottom site in Elliott Bay, the west reference site, was established at 47°35'32" N, 122°22'37" W to provide comparison with a site not influenced by the disposal but otherwise subject to a similar physical environment as the disposal site. Animals were collected at the reference site or caged there on the same schedule as at the experimental disposal site.

PART II: EXPERIMENTAL METHODS

Sampling Schedule

13. The timing and collection of the five test species are summarized here:

Species	Before Exposure*	Before Disposal**	During Disposal	After Disposal: Weeks 1	Weeks 2	Weeks 3	Months 1	Months 3	Months 6	Months 9
Collected at site										
English sole		X			X		X			
Pink shrimp		X			X		X	X	X	X
Held in cages										
Spot shrimp	X		X							
Sea cucumbers	X			X	X	X				
Mussels	X			X	X	X				

* Animals taken from an area remote from dumping site.

** Animals taken from the site on which dredged material was to be dumped.

Number of Animals per Sample

14. Because the number of animals was limited by availability and space in cages, the number included in each composite for analysis was different for each species:

English sole	5 per sample
Pink shrimp	14 per sample
Spot shrimp	10 per sample
Sea cucumber	3 per sample
Mussel	30 per sample

For animals collected at the site (i.e., English sole and pink shrimp), three samples were collected when sufficient numbers were available. For

the animals exposed in cages, four samples were obtained in all cases. Since there was only one site before exposure (i.e., the source/holding area remote from Elliott Bay), four samples were used to represent the preexposure data.

Collection of Animals Native to Site

15. English sole (Parophrys vetulus) and Alaska pink shrimp (Pandalus borealis) were collected by means of a Marinovich semiballoon, bottom otter trawl. Three replicate tows of 5-min duration (total time on the bottom) were carried out for each set of samples. If enough animals were obtained in a tow, they were analyzed separately. Otherwise, animals from separate tows were combined or, alternatively, animals from one tow were used to provide two or three samples. As soon as the animals were brought aboard the vessel, they were sorted, wrapped in aluminum foil, and put aside in a cool place.

16. Approximate sampling periods are indicated in this report to simplify the account. The exact sampling schedule is given below:

Sampling Period	Date	Site	Species
Before dumping	2/11/76	Disposal	English sole, pink shrimp
	2/13/76	W. Reference	English sole, pink shrimp
Two weeks after	3/22/76	Both	Pink shrimp
	3/22/76	Disposal	English sole
	3/23/76	W. Reference	English sole
One month after	4/12/76	W. Reference	English sole
	4/12/76	Both	Pink shrimp
Three months after	6/14/76	Both	Pink shrimp
Six months after	9/14/76	Disposal	Pink shrimp
	9/15/76	W. Reference	Pink shrimp
Nine months after	12/7/76	W. Reference	Pink shrimp
	12/7/76	Disposal	Pink shrimp*
	12/7/76	W. Reference	English sole*

* One sample only.

Exposure of Animals in Cages

During disposal operation

17. Spot shrimp (Pandalus platyceros) were collected at Whitney Point, Hood Canal, Washington, on 25 January and 27 January 1976. The shrimp were held at Mukilteo, Washington, in fiberglass holding tanks (1.8 m diam) flushed with unfiltered seawater at ambient temperature from Puget Sound until use, and were fed scraps of fish and mussels obtained nearby. Four samples of shrimp were removed on 27 February to determine the preexposure PCB level. The shrimp were exposed in vinyl-coated wire-mesh cages, 92 X 92 X 46 cm, with 10- by 10-mm openings between the 2-mm strands of coated wire. They were planted at the bottom on the disposal site on 27 February, left for 3 days, and recovered on 1 March 1976. A second set of shrimp were also exposed at the disposal site for 3 days between 2 and 5 March 1976. Cages were placed at the west reference site on both occasions. The first cage was never recovered. Because of heavy seas the second cage could not be found on 5 March but was spotted on 9 March. The only sample of spot shrimp from the west reference site was therefore exposed for 7 days. The samples were immediately wrapped in aluminum foil and stored in a styrofoam cooler.

After disposal operation

18. Sea cucumbers (Parastichopus californicus) collected by scuba divers in 12 m of water at Agate Pass, Washington, were held in tanks (see above) for about 5 weeks before use. They were not fed during this time but did completely consume the algae growing on the walls of the aquaria and appeared to be in good condition when placed in the cages. Mussels (Mytilus edulis) were obtained from the piers of the National Marine Fisheries Field Station at Mukilteo, Washington.

19. Sea cucumbers and mussels were exposed in collapsible cages, 244 X 86.4 X 86.4 cm, of 5.1- by 5.1-mm iron screen, supported on a 9.5-mm frame of cold-rolled steel. Two partitions of 3.2-cm nylon mesh

(about 12-thread) were placed 66 cm from the ends to give three sections. The end sections were 86.4 X 66 X 86.4 cm, and the central section was 112 X 86.4 X 86.4 cm. Sea cucumbers were placed in the central section and clumps of mussels in the end ones. One cage was placed at the bottom of Elliott Bay near the middle of the dump site, the other was placed at the west reference site. Each cage contained about 40 sea cucumbers initially. As animals were being placed in the cages, others were put aside to provide preexposure samples. The cages were placed in Elliott Bay on 9 March 1976. After 1, 2, and 3 weeks the cages were raised and the animals removed for analysis. During transportation and overnight storage the animals were held in seawater in plastic garbage cans.

Preparation of Animals for Analysis

20. All animals were transferred to the laboratory the day they were collected. They were held overnight at 3°C. If preparation the next day was not possible, they were wrapped tightly in aluminum foil, frozen, and held at -18°C. Before use they were thawed overnight at 3°C.

21. For analyses the animals were washed thoroughly in cold water to remove debris and sediment. Mussels were pulled from the clumps, scraped free of adhering fauna, mainly barnacles, and the largest chosen. The alimentary canal of English sole was removed, cut into several pieces, and scraped with a scalpel to remove the contents. The cleaned alimentary canal was included with the remainder of the fish. Sea cucumbers were squeezed to remove excess water as completely as possible. The intestines were separated and flushed with cold water to remove the contents before analysis. From an analytical viewpoint, sea cucumbers are far from ideal animals, since they hold an indeterminate amount of water and are prone to self-evisceration.

22. Whole animals were analyzed except for mussels, which were shucked and minced with scissors. Sea cucumbers, spot shrimp, and

English sole were frozen before grinding. Pink shrimp were cut up by hand with scissors. These precautions were necessary to obtain homogeneous samples.

Polychlorinated Biphenyl Analysis*

Extraction and purification

23. Extracts were obtained by the method of Reinert.[13] In this procedure the ground sample (10 g) was mixed at high speed (23,000 rpm) with isopropyl alcohol/benzene (1:1) for 5 min. The mixture was then diluted with hexane and boiled for 45 min. Hexane was added to replace the evaporated liquid. The hexane extract was filtered and purified by liquid chromatography on Florisil PR.

Quantitation

24. The PCB's in the purified extracts were quantitated with a Varian 600-D gas chromatograph with a tritium detector and a 5-ft by 1/8-in. glass column containing a mixture of equal parts of 15 percent QF-1 on 80/100 mesh Gas-Chrom Q and 10 percent DC-200 on the same support.[14] The curves were quantitated by measuring the heights of the nine peaks corresponding to the dominant peaks in Aroclor 1254, the reference standard. Measurement of nine peaks from curves of extracts of sea cucumbers was not possible because the last four peaks were too small. For sea cucumbers, therefore, standard curves for the five principal early peaks of Aroclor 1254 were used for quantitation. In all cases the peak that overlapped the pesticide DDE was omitted to avoid possible interference. Standard curves using a minimum of three concentrations of standard were prepared daily. The sensitivity throughout each run was ensured by frequent injection of standard solutions of Aroclor 1254.

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* All data are reported on the basis of parts per million (ppm), i.e., µg/g wet tissue, often stated as wet weight.

Duplicate Analyses

25. To assess the reproducibility of PCB analysis, 15 of the 123 samples included in this study were analyzed twice, starting with the homogenized tissue. The results of the duplicate analyses are presented in Table B1. The precision is well within the acceptable limit for PCB analysis. The mean relative standard deviation is 10.8 percent. The relative standard deviations for 11 of the samples were less than 10 percent. The others were 13.3, 22.2, 33.9, and 43.7 percent. The value of 33.9 percent for one sample of sea cucumbers is not unusual in analyses near the lower limit of detectability. The variability of the analyses of the other two samples of sea cucumbers is much smaller, 1.4 and 4.9 percent. Occasional variability of 13.3 and 22.2 percent is not unusual in chlorinated hydrocarbon analysis, especially when whole animals, including skin and skeleton, are analyzed. Only the value of 43.7 percent is abnormal. Samples of whole animals often lack the homogeneity necessary for consistent analysis.

Interlaboratory Calibration

26. To assess the accuracy of PCB analysis, extracts of tissue and sediment were analyzed both by the National Marine Fisheries Service (NMFS) laboratory and the University of Washington (UW), Department of Oceanography. The latter group performed the PCB determinations on the samples of water, particulate matter, and sediment collected in conjunction with the experimental disposal operation in Elliott Bay.

27. The values from the two laboratories are in excellent agreement (Tables B2 and B3). The mean relative standard deviation for the extracts provided by NMFS was 15.6 percent, for those from UW, 22.6 percent. The data for the extracts provided by NMFS (Table B2) indicate that the results obtained by the NMFS study method are very similar to those of the complex peak by peak system used by the UW. The values from the

UW on these samples are, on the average, 5 percent lower than the NMFS study values, comparing relative standard deviations of the individual laboratories. The extracts of sediments provided by the UW often were significantly different from those obtained from marine animals. The sediments contained a greater proportion of Aroclor 1260 than NMFS calibration standards. Nonetheless, the NMFS data were only 9 percent lower than those of the UW (Table B3). The values for two extracts (AS-413 and AS-418) provided by the UW were twice the values from the NMFS. These samples contained 20 to 30 percent Aroclor 1242, which is not generally found in that concentration in marine animals and which would be underestimated by NMFS calibration standards. Correction for 30 percent Aroclor 1242 gives 0.94 ppm for AS-418 and 1.25 ppm for AS-413, in better agreement with the UW data of 1.22 and 1.63 ppm, respectively.

PART III: RESULTS AND DISCUSSION

English Sole

28. Although data from the preliminary trawl of the pilot study indicated that English sole were present in Elliott Bay, they proved to be unavailable during much of the year. The researchers were able to collect only five complete sets of samples. At the disposal site fish were available only before dredging began and 2 weeks after disposal ceased. The PCB levels before disposal were substantially higher than those immediately following. The mean values beforehand were 2.28 ppm at the west reference site and 2.58 at the disposal site. Two weeks after disposal ceased, the corresponding values were 0.65 and 0.74 ppm. One month after disposal ceased, the value at the west reference site was 0.87 ppm. The range of PCB values was so broad that no conclusions could be drawn from the limited data (Table B4).

29. Fish are not ideal indicators of local pollution, in spite of the fact that they are traditional indicator organisms of widespread, chronic pollution. They may disperse widely and be exposed to various levels of PCB pollution. The absence of English sole from Elliott Bay during much of the season suggests that they migrate out of the area. Seasonal movement to different depths or areas are known to occur, but details of those migrations are not known. Nonetheless, English sole are reported to exhibit pronounced homing behavior, perhaps down to individual territory.[15] Discrete populations may well exist, in spite of migration, since the incidence of parasitic infestation seems to be related to specific locations within Puget Sound.[16]

Alaska Pink Shrimp

30. Comparison of the mean values for PCB levels in Alaska pink shrimp collected at the two sites does not indicate any change related to disposal. On two occasions (before dredging began and 6 months after

disposal ceased), the PCB levels in shrimp from the disposal site were substantially higher than in those from the west reference site. The PCB level in shrimp at the west reference site appears to have risen slightly over the period of the study, from 0.28 to 0.54 ppm, but may not be significant because of the large variation between replicate samples (Table B5).

31. In addition, Alaska pink shrimp, the more common pink shrimp in Puget Sound, were not consistently present at the west reference site. When Alaska pink shrimp were not available, 7 samples in all, Oregon pink shrimp, Pandalus jordani, were substituted. Although data for P. jordani are limited, they do not exhibit any obvious species difference in PCB accumulation from P. borealis. The fact that pink shrimp taken at the disposal site were nearly exclusively P. borealis, whereas those from the west reference site were often mainly P. jordani, suggests some kind of environmental difference between the sites. The ecological distinctions between P. borealis and P. jordani are not currently known. The distribution of populations of P. borealis between the two sites and even from sampling period to sampling period at each site may also be distinctly different because the standard deviations for replicate values of PCB's are notably disparate.

Spot Shrimp

32. Exposure during the dumping itself did not increase the concentration of PCB's in spot shrimp (Table B6). The relative standard deviation of the samples taken before exposure, 33.1 percent, was so large that a substantial uptake of PCB's would have been necessary to provide a statistically significant increase. The levels at the two sites appear to be the same.

33. Few data have been collected about the PCB levels of marine animals from Hood Canal. Less than 0.01 ppm PCB's were found in sole or

sculpin.* The level in the spot shrimp before exposure, 0.174 ppm, may have resulted from uptake during holding at Mukilteo, Washington, and may exceed that in animals from Hood Canal. Animals with a lower and more consistent PCB content might have yielded statistically significant data on the effect on spot shrimp of exposure to PCB-laden dredged material.

Sea Cucumbers

34. The PCB content of all samples of sea cucumbers was less than 0.1 ppm, the minimum amount to be quantitated for this contract. In an attempt to evaluate minimal accumulation of PCB's, the lower limit of detection was decreased to about 0.035 ppm, depending on the daily fluctuations in sensitivity of the detector. Only a minimal increase in PCB concentration was observed, from 0.04 to 0.07 ppm, in 3 weeks at the west reference site (Table B7). At the disposal site the maximum concentration was 0.06 ppm. Because the concentrations of PCB's found in sea cucumbers were so close to the lower limit of quantitation, the apparent increases in PCB's are not significant. Sea cucumbers did not accumulate chlorinated hydrocarbons to any marked degree under the conditions of the experiment.

35. P. californicus is a detritus feeder (i.e., it eats material falling through the water). Confined animals were in contact with bottom sediment and debris, including the dredged material, which could filter through the mesh bottom of the cage. Consequently, the sea cucumbers were exposed to the PCB-laden material through the skin, through direct transfer from the dredged material to the gill membrane, through respiration of any PCB's which leached out of the dredged material into the water, and through ingestion of particles of sediment which were stirred up. None of these routes appear to have provided a means

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* Personal communication, 15 June 1977, U. S. Environmental Protection Agency, Gulf Breeze, Florida.

accumulation of PCB's by P. californicus. Sea cucumbers contain ry little fat, 0.06 ± 0.02 percent, to dissolve these lipophilic com- unds and appear to eliminate any that may pass through them as the sult of respiration, feeding, or contact with skin or gills.

Mussels

36. The levels of PCB's in mussels exposed at the west reference te remained essentially at the preexposure value (Table B8). Before posure the mussels contained 0.12 ppm; the mean combining the three posure periods at the west reference site was 0.11 ppm. After 2 eks, mussels caged at the dump site showed a slight increase in PCB vels, from 0.12 to 0.20 ppm. This trend continued at the 3-week mpling also, but was obscured by the great variation between repli- tes. The relative standard deviation for all samples of mussels nged from 8.4 to 54.9 percent. Similar variation was found in samples intertidal mussels (Mytilus californianus): the relative standard viations were 26.6 and 23.4 percent for two sets of 12 samples con- ining 5 animals each.* Butler found that estuarine samples consist- g of 10 replicates of 15 oysters or 25 fish yielded standard errors ounting to 15 to 30 percent of the arithmetic means.[17]

37. The final PCB concentration of mussels at the disposal site, 21 ppm, was similar to that found in confined mussels exposed in the wamish River for up to 7 weeks and in mussels living naturally in the ver.[7] In mussels exposed on the bottom in 35 m of water near the wer outfall at Palos Verdes, California, the PCB concentration creased from 0.01 ppm initially to 0.26 ppm after 3 weeks and 0.56 ppm ter 13 weeks.[6]

Taken from Appendix Table A7 of Reference 4.

38. From this limited study it was not possible to draw conclusions about the effect on mussels of dumping the PCB-laden dredged material on the experimental site. In the first place, in spite of the current levels of PCB's in the Duwamish River, mussels do live there. Secondly, since the experimental site is directly downstream from the river, it receives more of the PCB burden from the river and, therefore, was more polluted initially than the reference site. The latter, which is west of the mouth of the river proper, is protected from the main impact from the river. If, as a result of disposal, the level of available PCB's at the disposal site had increased dramatically, however, greater increases in the PCB levels in mussels would have been anticipated. The data on the caged mussels show that no marked increase in PCB's resulted from the experimental disposal operation.

39. The use of mussels containing a lower level of PCB's initially might well increase the possibility of observing a statistically significant change in PCB concentration during exposure in Elliott Bay. The mussels used in this study contained 0.12 ppm PCB's before exposure in Elliott Bay. In 1972 it was found that mussels from Clam Bay, Washington, on the west side of Puget Sound contained 0.092 ppm PCB's. Beug et al.[7] found as low as 0.010 ppm in certain areas of southern Puget Sound. Specimens from a less polluted site might have accumulated a statistically significant amount of PCB's.

40. A second problem with the mussels was the variation in size. Although the mean length for all samples appeared to be fairly consistent, 4.30 ± 0.17 cm, the variation both within samples and between samples was rather great. The relative standard deviation of the length for individual samples ranged from 11.0 to 23.3 percent. The smallest animal in a sample ranged from 2.2 to 3.6 cm, the largest, from 5.2 to 7.2 cm. This lack of consistency in itself is a possible explanation for the large variation in PCB content between samples, since the rate of accumulation appears to vary with size.

Methodology

41. Except for the sea cucumbers, the PCB residues were quantitated by measuring the nine peaks corresponding to the major peaks in Aroclor 1254 (omitting the peak with a retention time similar to that of DDE). This technique was used to take into account the presence in the samples of Aroclor 1260, to the extent of about 15 to 30 percent of the total PCB's. Comparative analyses showed that approximately 90 percent of the total Aroclors which were accounted for by use of a mixed standard of Aroclors 1254 and 1260 were measured by using the nine peaks of Aroclor 1254. Because the last four peaks from sea cucumber extracts were very small, samples of sea cucumbers were quantitated by comparison with the five largest peaks of Aroclor 1254.

42. In this laboratory extracts for PCB analysis are normally chromatographed on silica gel to separate the PCB's from DDT (dichlorodiphenyltrichloroethane) and its metabolites, TDE (dichlorodiphenyldichloroethane), and DDE (dichlorodiphenyldichloroethylene), which can interfere with PCB quantitation. The levels of PCB's in some of the samples for this study were so low that quantitation was difficult. Since silica gel separations of DDT from PCB's are somewhat variable, the procedure was eliminated to achieve more consistent data near the lower limit of detection. Extracts from English sole, which contained higher levels of PCB's, could have been treated to remove the DDT but the results would not have been directly comparable to the remaining data. To obtain maximum internal consistency all samples were quantitated without removing DDT.

43. The extent of interference was limited, however, since the levels of DDT were low. The levels of DDT found in marine samples from this area have always been substantially lower than in other regions of the United States.[18] Although DDT itself cannot be quantitated accurately without PCB separation, DDE, a major component of DDT residues in the marine environment, can be estimated in the presence of PCB's. Most of the samples contained less than 0.01 ppm DDE. The English sole contained up to 0.05 ppm DDE occasionally, and one sample contained 0.115 ppm.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

44. No obvious changes were observed in the PCB levels in selected marine animals in Elliott Bay as the result of disposal of PCB-laden dredged material at the experimental site. English sole and pink shrimp collected at both the reference and the disposal site prior to dredging already contained substantial amounts of PCB's. The variation between samples was such that effects from disposal could not be separated from fluctuations between samples.

45. Spot shrimp caged at the experimental site for 3 days during dumping did not accumulate PCB's to significant levels above background. Similarly, sea cucumbers exposed for up to 3 weeks after disposal ceased showed no change in PCB level.

46. The experimental disposal operation did not create a flux of PCB's great enough to concentrate in mussels to a marked extent. A small increase in PCB concentration in mussels did occur during exposure for 3 weeks at the disposal site. The increase in PCB levels may have been related to the disposal at the experimental site but alternatively may have resulted from long-term PCB pollution from the Duwamish River in the form of PCB-laden particulate matter either in the water column or precipitated onto the bottom.

47. Location of the disposal site in a polluted area (i.e., directly downstream from a polluted river) introduces additional variables and restricts assessment of the parameter under consideration. To maximize the value of a study such as this, outside variables must be reduced as far as possible.

48. Use of animals with lower initial levels of PCB's in the caging studies might have provided more definitive data about possible transfer of PCB's as the result of disposal of PCB-laden dredged material.

49. With the exception of mussel samples, which contained 30 animals, the number of animals per sample was probably too small. The limited number of animals, 3 sea cucumbers, 5 English sole, 10 spot

shrimp, and 14 pink shrimp, did not adequately compensate for the variation between individuals. In order to obtain more conclusive data, a minimum of 15 mollusks or 25 fish or other marine organisms is recommended.

50. Since increasing the number of specimens increases the cost of handling (only in some cases, since the limited total mass of pink shrimp could only be homogenized by hand with scissors), the practice of removing the stomach and intestinal contents might be eliminated. This procedure is extremely time-consuming and may not be warranted. Although animals are occasionally depurated briefly in flowing water to remove adhering and ingested sediment, removal by dissection and flushing or scraping is unusual.

51. Consistency in size of mussels might contribute to more consistent data on PCB accumulation.

52. Sea cucumbers, first used in this study to monitor PCB pollution, did not accumulate these chlorinated hydrocarbons under the conditions at the test site. Since the sea cucumber is a difficult animal to handle, it does not appear to be a useful organism for monitoring pollution by chlorinated hydrocarbons.

53. The limited baseline information, a single trawl in December 1975, did not provide adequate data for choosing suitable species. A resident species, available throughout the year and susceptible to accumulation of PCB's, is needed to assess the possible transfer of PCB's from dredged material to a marine animal.

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Table B1

Reproducibility of PCB Analysis

Sample Number	Analysis, ppm #1	#2	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent
		English Sole			
1	3.66	3.55	3.60	0.078	2.2
2	1.51	1.25	1.38	0.184	13.3
3	1.05	1.44	1.24	0.276	22.2
4	3.63	3.18	3.40	0.318	9.3
5	3.04	3.28	3.16	0.170	5.4
6	1.69	1.66	1.68	0.021	1.3
		Pink Shrimp			
1	0.208	0.394	0.301	0.132	43.7
2	0.708	0.785	0.746	0.054	7.3
3	0.626	0.575	0.600	0.036	6.0
4	0.549	0.528	0.538	0.015	2.8
		Spot Shrimp			
1	0.232	0.222	0.227	0.007	3.1
2	0.171	0.158	0.164	0.009	5.6
		Sea Cucumbers			
1	0.038	0.062	0.050	0.017	33.9
2	0.049	0.050	0.050	0.001	1.4
3	0.074	0.069	0.072	0.004	4.9
Mean Relative Standard Deviation (for all samples analyzed twice)					10.8

Table B2

PCB Intercalibration Between NMFS and UW,
Extracts of Animal Tissues Provided by NMFS

Sample No.	NMFS	UW	Mean	Standard Deviation	Relative Standard Deviation Percent
V1758	0.164	0.100	0.132	0.045	34.3
V1760	0.107	0.082	0.094	0.018	18.8
V1772	0.168	0.170	0.169	0.001	0.8
V1776	0.168	0.161	0.164	0.005	3.0
V1786	0.680	0.707	0.694	0.019	2.8
V1795	0.333	0.253	0.293	0.057	19.3
V1797	0.190	0.130	0.160	0.042	26.5
V1798	0.821	0.990	0.906	0.120	13.2
V1801	0.291	0.232	0.262	0.042	15.9
V1803	0.524	0.406	0.465	0.083	17.9
V1804	0.593	0.566	0.580	0.019	3.3
V1841	0.265	0.427	0.346	0.115	33.1
V1857V	3.66	4.43	4.04	0.544	13.5
V1868F	1.66	2.10	1.88	0.311	16.5
V1908(1:10)	5.90	4.78	5.34	0.792	14.8
Mean Relative Standard Deviation					15.6

Table B3

PCB Intercalibration Between NMFS and UW,
Extracts of Sediments Provided by UW

AS No.	NMFS	UW	Mean	Standard Deviation	Relative Standard Deviation Percent
442	0.350	0.305	0.328	0.032	9.7
438	0.550	0.684	0.617	0.095	15.4
446	0.574	0.574	0.574	0	0
412	0.341	0.497	0.419	0.110	26.3
416	0.538	0.476	0.507	0.044	8.6
422	0.259	0.184	0.222	0.053	23.9
424	0.018	0.029	0.024	0.008	32.4
426	0.019*	0.031	0.025	0.008	33.9
441	0.343	0.306	0.324	0.026	8.1
443	0.492	0.592	0.542	0.071	13.0
417	0.347	0.243	0.295	0.074	24.9
418	0.659	1.222	0.940	0.398	42.4
170	0.398	0.294	0.346	0.074	21.3
413	0.873	1.629	1.251	0.535	42.7
421	0.016	0.031	0.024	0.011	44.2
427	<0.012	0.009	0.010	0.001**	14.1
Mean Relative Standard Deviation					22.6

* 0.032 before correction for an extraneous peak.

** In calculation used 0.011 for <0.012

Table B4

PCB's in English Sole (Parophrys vetulus)

Sampling Period	West Reference Site			Disposal Site		
	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent
Before disposal	2.28	1.18	51.6	2.58	1.36	52.8
After disposal:						
2 weeks	0.65	0.05	7.6	0.74	0.52	70.4
1 month	0.87	0.22	24.9	*		
3 months	*			*		
6 months	*			*		
9 months	5.90**					

Note: Values based on 3 samples; individual data are listed in Table B9.

* No samples.

** One sample only.

Table B5

PCB's in Alaska Pink Shrimp (Pandalus borealis)

Sampling Period	West Reference Site			Disposal Site		
	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent
Before disposal	0.277	0.074	26.7	0.505	0.113	22.3
After disposal:						
2 weeks	0.290	0.203	70.0	0.302	0.027	8.9
1 month	0.333*	0.072	21.6	0.327	0.049	14.9
3 months	0.421	0.219	52.0	0.397	0.054	13.6
6 months	0.356**	0.038	10.7	0.819	0.037	4.5
9 months	0.539*	0.018	3.3	0.626†	---	---

Note: Values based on 3 samples; individual data are listed in Table B10.

* All Oregon pink shrimp (P. jordani).

** One sample Oregon pink shrimp.

† One sample only.

Table B6

PCB's in Spot Shrimp (Pandalus platyceros) Exposed During Disposal Operations

Exposure (days)	Site	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent
0	----	0.174	0.058	33.1
7	West Reference	0.190	0.024	12.4
3	Disposal	0.208	0.023	11.3
3	Disposal	0.185	0.028	14.9

Note: Values based on 4 samples; individual data are listed in Table B11.

Table B7

PCB's in Sea Cucumbers (*Parastichopus californicus*)

Exposed After Disposal

Exposure (weeks)	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent
0	0.040	0.008	20.4
	West Reference Site		
1	0.058	0.018	31.9
2	0.060	0.013	21.3
3	0.070	0.005	6.7
	Disposal Site		
1	0.054	0.005	10.8
2	0.052	0.012	24.2
3	0.060	0.018	30.3

Note: Values based on 3 samples; individual data are in Table B12.

Table B8

PCB's in Mussels (*Mytilus edulis*) Exposed After Disposal

Exposure (weeks)	Mean ppm	Standard Deviation ppm	Relative Standard Deviation percent
0	0.122	0.012	9.8
	West Reference Site		
1	0.103	0.054	52.7
2	0.131	0.028	21.4
3	0.100	0.008	8.4
	Disposal Site		
1	0.108	0.059	54.9
2	0.200	0.038	19.0
3	0.206	0.063	30.4

Note: Values based on 3 samples; individual data are listed in Table B13.

Table B9

PCB's in English Sole: Individual Data

Sampling Period	Sample	West Reference, ppm	Disposal Site, ppm
Before disposal	1	1.51	3.66
	2	3.63	1.05
	3	1.69	3.04
	$\bar{X}$	2.28	2.58
After disposal:			
2 weeks	1	0.680	0.821
	2	0.678	0.185
	3	0.593	1.22
	$\bar{X}$	0.650	0.742
1 month	1	0.771	
	2	0.723	
	3	1.12	
	$\bar{X}$	0.871	
9 months	1	5.90	

Note: 5 fish per sample.

Table B10

PCB's in Alaska Pink Shrimp: Individual Data

Sampling Period	Sample	West Reference, ppm	Disposal Site, ppm
Before disposal	1	0.208	0.635
	2	0.355	0.440
	3	0.268	0.440
	$\bar{X}$	0.277	0.505
After disposal:			
2 weeks	1	0.190	0.333
	2	0.157	0.291
	3	0.524	0.283
	$\bar{X}$	0.290	0.302
1 month	1	0.400*	0.334
	2	0.257*	0.372
	3	0.343*	0.275
	$\bar{X}$	0.333	0.327
3 months	1	0.241	0.441
	2	0.357	0.337
	3	0.665	0.414
	$\bar{X}$	0.421	0.397
6 months	1	0.314	0.778
	2	0.389	0.830
	3	0.364*	0.850
	$\bar{X}$	0.356	0.819
9 months	1	0.708	0.626
	1	0.519*	
	2	0.549*	
	3	0.550*	
	$\bar{X}$	0.539	

Note: 14 animals per sample.

* Oregon pink shrimp.

Table B11

PCB's in Spot Shrimp: Individual Data

Exposure (days)	Sample	PCB's, ppm
0	1	0.110
	2	0.171
	3	0.250
	4	0.164
	$\tilde{X}$	0.174
	West Reference Site	
7	1	0.214
	2	0.206
	3	0.177
	4	0.164
	$\tilde{X}$	0.190
	Disposal Site	
3	1	0.232
	2	0.225
	3	0.192
	4	0.185
	$\tilde{X}$	0.208
3	1	0.171
	2	0.216
	3	0.154
	4	0.198
	$\tilde{X}$	0.185

Note: 10 shrimp per sample.

Table B12

PCB's in Sea Cucumbers: Individual Data

Exposure (weeks)	Sample	PCB's, ppm	PCB's, ppm
0	1	0.038	
	2	0.034	
	3	0.036	
	4	0.052	
	$\bar{X}$	0.040	
		West Reference Site	Disposal Site
1	1	0.080	0.050
	2	0.035	0.054
	3	0.056	0.061
	4	0.061	0.052
	$\bar{X}$	0.058	0.054
2	1	0.064	0.033
	2	0.044	0.059
	3	0.059	0.055
	4	0.075	0.059
	$\bar{X}$	0.060	0.052
3	1	0.068	0.041
	2	0.073	0.049
	3	0.064	0.071
	4	0.074	0.080
	$\bar{X}$	0.070	0.060

Note: 3 animals per sample.

Table B13

PCB's in Mussels: Individual Data

Exposure (weeks)	Sample	PCB's, ppm	PCB's, ppm
0	1	0.107	
	2	0.121	
	3	0.136	
	4	0.123	
	$\bar{X}$	0.122	
		West Reference Site	Disposal Site
1	1	0.168	0.168
	2	0.122	0.151
	3	0.042	<0.060
	4	0.080	0.055
	$\bar{X}$	0.103	0.108
2	1	0.122	0.176
	2	0.166	0.206
	3	0.136	0.168
	4	0.099	0.252
	$\bar{X}$	0.131	0.200
3	1	0.097	0.118
	2	0.090	0.265
	3	0.110	0.215
	4	0.102	0.227
	$\bar{X}$	0.100	0.206

Note: 30 animals per sample.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Stout, Virginia F
Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Washington; Appendix B: Role of disposal of PCB-contaminated sediment in the accumulation of PCB's by marine animals / by Virginia F. Stout, Laura G. Lewis, Northwest and Alaska Fisheries Center, Seattle, Washington. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.
27, [13] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-24, Appendix B)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Interagency Agreement WESRF 76-90 (DMRP Work Unit No. 1A10B)
References: p. 26-27.

1. Dredged material. 2. Marine animals. 3. Polychlorinated biphenyls. 4. Puget Sound. 5. Uptake. I. Lewis, Laura G., joint author. II. United States. Army. Corps of Engineers.

(Continued on next card)

Stout, Virginia F
Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Washington; Appendix B: Role of disposal of PCB-contaminated sediment ... 1977. (Card 2)

III. United States. National Marine Fisheries Service. Northwest and Alaska Fisheries Center. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-24, Appendix B.
TA7.W34 no.D-77-24 Appendix B